(2)

AD

TECHNICAL REPORT ARCCB-TR-90020

HAZARDS AND SAFEGUARDS OF HIGH PRESSURE HYDRAULIC FATIGUE TESTING

BRUCE B. BROWN

JULY 1990

US ARMY ARMAMENT RESEARCH,
DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DESTRUCTION NOTICE

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

For unclassified, unlimited documents, destroy when the report is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCCB-TR-90020	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HAZARDS AND SAFEGUARDS OF HIGH PRESSURE HYDRAULIC FATIGUE TESTING		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bruce B. Brown		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army ARDEC Benet Laboratories, SMCAR-CCB-TL Watervliet, NY 12189-4050		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 6126.24.1BL0.0AR PRON No. 1A72ZH7QUMSC
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army ARDEC Close Combat Armaments Center Picatinny Arsenal, NJ 07806-5000		12. REPORT DATE July 1990 13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the ASME 1987 Pressure Vessel and Piping Conference, San Diego, CA, 28 June through 2 July 1987.
Published in Proceedings of the Conference.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fatigue (Mechanics), Failure (Mechanics), High Pressure, Hydraulics, Pressure Vessels, Fragmentation, Large Components, Material Handling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The creation and transfer of hydraulic pressure at the 690-MPa (100,000-psi) level is in itself hazardous. When this is used to fatigue cycle large pressure vessels to failure, the potential for catastrophic accidents is always present. This report summarizes the experience gained over several years of this operation wherein several hundred pressure vessels have been successfully taken to fatigue failure. Although accidents still take place, we have eliminated most of the personnel hazards, greatly reduced equipment

(CONT'D ON REVERSE)

20. ABSTRACT (CONT'D)

damage, and are constantly striving to detect and eliminate any existing or new hazards. The hazards and safeguards are grouped into four areas of consideration: high pressure fluids, fragments, large components, and material handling. Keywords: → to field 19

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

Page

ACKNOWLEDGEMENT

Special thanks are extended to Dan Corrigan for providing the photographs for this report.

INTRODUCTION

In our laboratory, pressure vessels, mostly cannon tubes, are tested to determine pressure effects up to burst and fatigue behavior to failure. These tests are conducted using hydraulic fluid with pressure generated by large intensifiers. We are currently operating three test units for fatigue and static testing up to 690 MPa (100,000 psi) and a static-only unit to 1000 MPa (150,000 psi). Figure 1a is a schematic of our test units, while Figure 1b is a view of a test cell containing one test unit. Each test cell is a 6-m by 6-m (20-ft by 20-ft) room with a steel face on the operator's side and steel or masonary walls on the other sides. The cell roofs are multilayered wooden sections removable to accommodate the movement of specimens and equipment by crane. The front wall contains operating controls, a viewing window, and an access door.

The specimens tested range from 30-mm to 210-mm bore size and weigh up to 1400 Kgs (3000 lbs). Normal operating pressures range from 69 MPa (10 Ksi) to 690 MPa (100 Ksi). Figure 1c shows a large specimen mounted in a mandrel for testing. The mandrels, custom-made for each specimen, are fabricated from maraging steel and have a finite life in the order of six to ten specimens. Figure 1d shows a small specimen mounted in a press for testing. A press is only used for specimens with moderate end loads to avoid early fatigue failure of the press tie rods.

In the thirty years this laboratory has been in constant operation, we have had accidents, fortunately with only minor injuries to personnel, although with some severe damage to equipment. We have learned from each accident and have engineered safety devices and revised operating procedures to limit exposure to personnel injury and equipment damage. Perhaps the greatest factor in our

safety is the attitude instilled in engineers and technicians to respect the pressures and forces involved.

To organize the hazards and safeguards inherent to high pressure testing, the field can be divided into four categories: high pressure fluids, fragments, large components, and material handling. Each of these categories is fairly unique in its hazards and safeguards.

HIGH PRESSURE FLUIDS

We operate the high pressure end of our hydraulic test systems using fluids capable of flow up to the test pressure. Up to 690 MPa (100,000 psi), synthetic oils especially formulated for this pressure are used. Above this pressure, a water-glycol mix is used. High pressure leaks are certain to occur and must be planned for. The specimen failure will always release fluid, but there is even more frequent leakage from piping and seal failures, for as we fatigue out the test specimens, we are also fatiguing all the other components of the test system. It must be recognized that fluid at 50 MPa (5000 psi) can be fatal in the form of a jet and even droplets can penetrate the skin. With fluid operating up to twenty times this level, this hazardous condition must be appreciated and not looked upon as a plumbing problem. Figure 2 shows typical piping failures which often occur and can be the source of high pressure jets.

The safeguards necessary for this high pressure fluid problem are a careful choice of the operating fluid and the isolation of personnel from leaks. Choosing the fluid is difficult since most available fluids are flammable petroleum bases or toxic compounds. Both obviously should be avoided for safety reasons. We avoid water bases because of the potential environmental effects on specimens and lubrication problems. Our test cells provide isolation of personnel from the fluids with the access door containing an electrical interlock

that turns off all the pumps and dumps pressure upon opening. Each test cell is equipped with an exhaust fan to evacuate vapor. One area of risk is the tendency to bypass the door interlock to locate leaks from inside the cell. This can usually be avoided by first looking for fluid spills and hot spots without fluid pressure and, if necessary, using low pressure for leak detection. A more serious fluid pressure problem arises when pressure becomes trapped in a specimen.

The trapped pressure condition is caused when the fluid exit path from the specimen is checked by hydraulic seals breaking up and jamming in the pressure port or by internal tooling shifting to block fluid exit. Since both of these causes result in a check valve action, the entrapped fluid stays at or near maximum pressure. One way of detecting trapped fluid is by the strain reaction of the specimen. The strain recorder trace remains near the peak of the cycle and does not return to zero between cycles. A second indication of trapped pressure is a sudden increase in cyclic rate due to the decreased amount of fluid being transferred. Since this trapped fluid is usually at or near full pressure and the specimen and tooling have experienced some degree of fatigue damage, the experimenter must approach any pressure release actions with the same caution as if he were defuzing a bomb. Figure 3 shows the possible causes of blockage which must be considered in the depressurizing process.

The depressurizing steps must be taken with full appreciation that pressure can suddenly release at any time with a high pressure fluid jet and flying metal parts. Further cycling at lower or higher pressures may dislodge the blockage and should be the first step, followed by waiting overnight with the hope of slow leakage. Further actions must be taken with maximum shielding and remote operation. These are removing the pressure pipe and cone seal, probing and

drilling the inlet port, unscrewing the closure retaining nut of a mandrel using high torque fixtures, and as a last resort, drilling through the specimen wall. Figure 4a shows the massive fixtures made to unscrew a mandrel nut. With the trapped pressure, 5400 joules (40,000 ft-lb) of torque were required to move the nut. Figure 4b shows the arrangement to drill through the specimen wall by remote operation. In this case we were able to locate the drilled hole so that with a shift of the closure and seal location, we could subsequently resume test cycling the specimen. Since our specimens are valuable and scarce at the time they are tested, extreme measures are warranted to avoid their destruction in the depressurizing process.

FRAGMENTS

The hazard category of fragments includes pieces of failing specimens and various small items such as fasteners propelled by stress or fatigue failure. All of our specimens are eventually failed, and there is the expectation that this failure can result in high velocity fragmentation. This has been experienced when brittle materials such as titanium, maraging steel, and filament-wound composites are tested. Figure 5a shows the fragmentation failure of a titanium jacket that projected a fragment with enough force to sever a wiring conduit. Prior experiences with brittle steels showed that the 50-mm (2-in.) safety glass window and the 12-mm (½-in.) steel cell wall could be pierced. An extra steel sheet has been installed behind the control panels and a steel grate placed behind the windows to avoid fragment penetration. Specimens expected to fragment are now run with local shielding by metal tubes and/or cable wrappings. The fragmentation of filament-wound composites, as shown in Figure 5, does not present the impact problem of metal fragments, but does spray the test cell with

fiber particles. Due to the hazard of skin contact with sharp fibers, we also confine these with local shielding to limit the cleanup hazard.

All of our specimens are tested using a metal filler bar to minimize the contained fluid volume, thus limiting the stored energy available for fragmentation. Using a liquid pressure medium rather than gas pressure further reduces the stored energy. Lowering the stored energy lessens the fragmentation hazard.

LARGE COMPONENTS

In our tests of large pressure vessels, which are under high internal pressure and are carried to failure, the severe problem of massive flying objects is presented. A typical specimen with its test mandrel can weigh 1400 Kgs (3000 lbs) and fracturing of the mandrel can provide 1500 tons of driving force. The test mandrels have a finite life and can be expected to last through six to ten specimens, but material or heat treatment problems can cause failure in a few cycles. We have experienced several catastrophic mandrel failures where both the tube and the mandrel flew through the cell roof. Fortunately, no one was injured, but equipment was extensively damaged. Figure 6a shows a recent mandrel failure. Mandrels are made from maraging steel to allow drilling of the long pressure port and finish machining before heat treatment. Although the nominal fatigue resistance of maraging steel is better than alloy steel, we have found that it is more notch sensitive to fatigue and drastically degrades with small constituent variations.

To avoid this safety hazard, first we improved the mandrel engineering by lessening the stress at the root of threads and section changes and by tight metallurgical requirements. Secondly, we applied ultrasonic inspection to detect and measure mandrel cracks, as shown in Figure 6b. This is done by transmitting the beam end to end and noting signal interruptions caused by crack

surfaces. Some skills and experience are necessary to differentiate cracks from the signal return due to threads, section changes, and the pressure port. Suspected cracks can be verified by magnetic particle surface checks. Our crack measurements have been accurate enough to allow continued operation of cracked mandrels using fracture mechanics estimates of their remaining life.

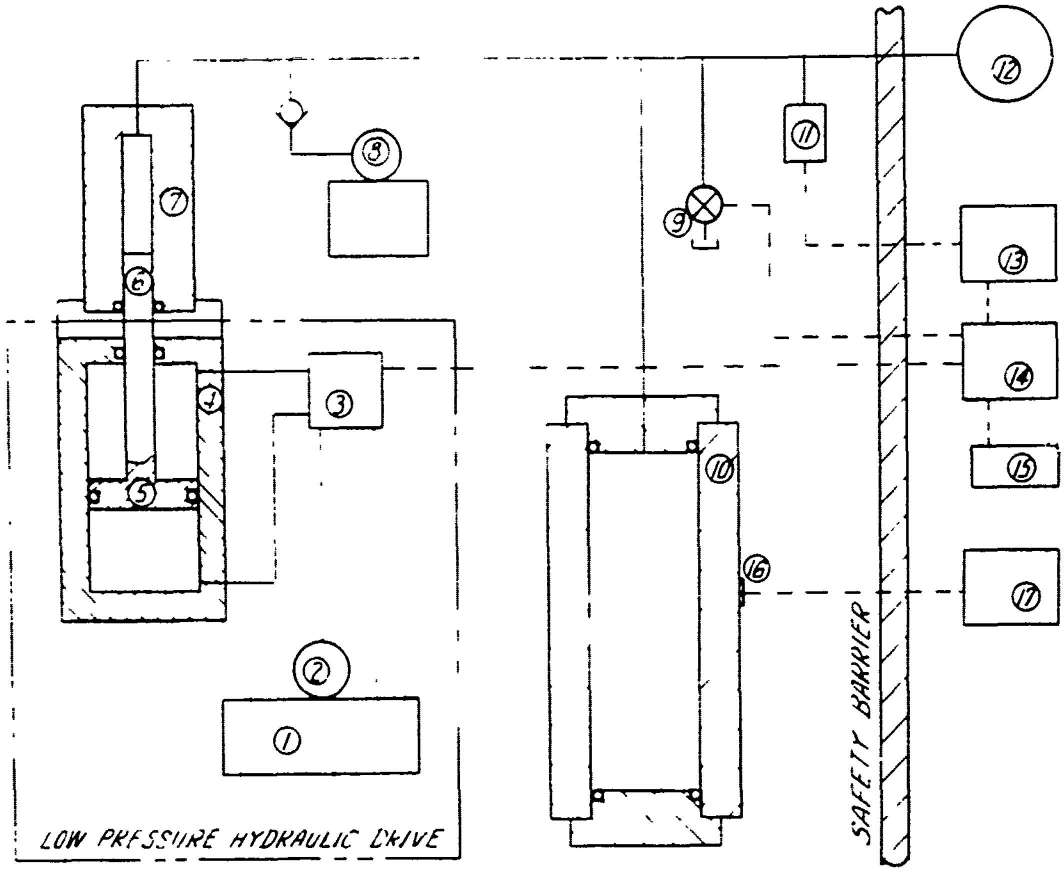
A final measure to prevent mandrel and specimen flights is the adoption of restraints. A mandrel failure at or near the top would project the mandrel out of the specimen. To prevent this we incorporated simple shock absorbers (Figure 6c) made from ¾-inch bolts enclosed in 1-inch copper water tubing. The bolts are attached to the specimen through the lift ring, while the bases of the copper tubes rest on the mandrel nut. Relative motion of the mandrel to the tube causes the tubes to collapse, absorbing energy, with the available stroke long enough to release the closure seal. If the mandrel fails through its larger bore section, the action will propel both the mandrel and the tube upward. To limit this action, we use a cable restraint (Figure 6d) tying the specimen to the mandrel base plate. A steel cable is loosely laced between four 'eyes' on both the tube and the base plate with a long overlap of cable ends. Two cable clamps are used on the cable ends. Upon mandrel failure, there is enough cable slack to separate the closure seal and through cable stretching and sliding of the clamps, the energy is absorbed. Since using this system, we have had four mandrels fail at the top and two at the bottom with the restraint systems fully confining the specimen and mandrel movements. The top failures compressed the copper tubes, and in one case, stretched the bolts. The bottom failures stretched the cables to partial failure at the attachment points and slipped the clamps. By greatly decreasing mandrel failures and incorporating the restraints, we feel that the mandrel failure safety problem is properly controlled.

MATERIAL HANDLING

Our most frequent injury problem has been in handling the large tubular specimens. These are inherently smooth, round, oil-coated, and heavy. For most specimens we machine a circumferential groove outboard of the pressure seal at one end and fit a lift ring into the groove. The circumferential groove placed outside the pressurized zone does not affect the fatigue behavior of the specimen and is used for crane lifts, to anchor the shock absorbers, and by including index markings, to provide degree locations for specimen inspection. On the specimens being tested in a press that must be slid into place by hand, we provide a wide base plate to prevent tipping. Other areas of concern are to avoid manhandling specimens, as is the normal tendency of an eager worker, and to diligently detect and scrap damaged lifting components such as cables and eyebolts.

SUMMARY

From our experience in thirty years of hydrostatic testing large specimens, two factors stand out: (1) injuries have almost exclusively occurred to new workers who have not yet learned to respect the pressures, forces, and weight involved, and (2) you must always expect the worst to happen--carelessness assures that it will. In conclusion, high pressure hydraulic testing requires careful attention to all four areas of safety hazards: pressurized fluid, fragmentation, flying components, and material handling.



LOW PRESSURE	HIGH PRESSURE	CONTROLS
1 OIL RESERVOIR & COOLER	6 DISPLACEMENT RAM	11 PRESSURE TRANSDUCER
2 PUMP 3-5 KSI	7 HIGH PRESSURE HEAD	12 PRECISION HYD. GAUGE
3 CONTROLLED VALVING	8 FLUID REPLENISHMENT PUMP & RESERVOIR	13 CHART RECORDER
4 CYLINDER	9 DUMP VALVE	14 OPERATING CONTROLS
5 PISTON	10 TEST SPECIMEN SEE FIG A2	15 CYCLE COUNTER
		16 STRAIN GAUGE
		17 STRAIN RECORDER

Figure 1a. System schematic with intensifier for up to 690 MPa (100 Ksi) pressure, specimen, piping, and controls.

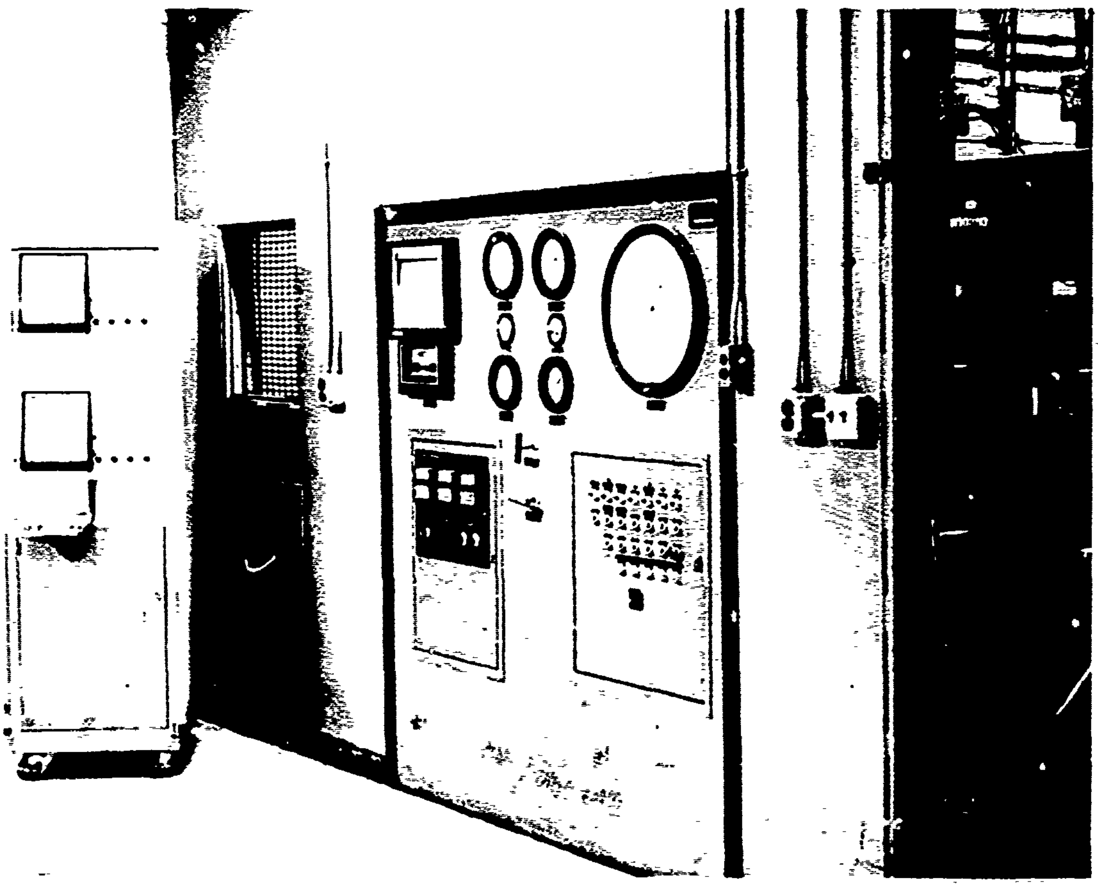


Figure 1b. Test cell with pressure system inside cell and exterior controls.

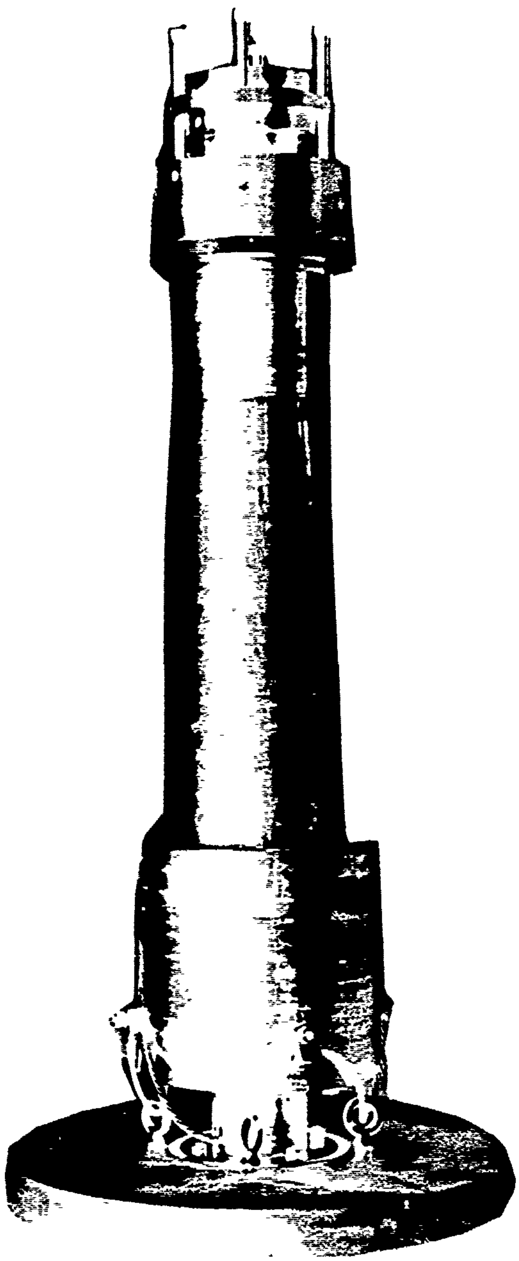


Figure 1c. Specimen with internal mandrel supporting closures.

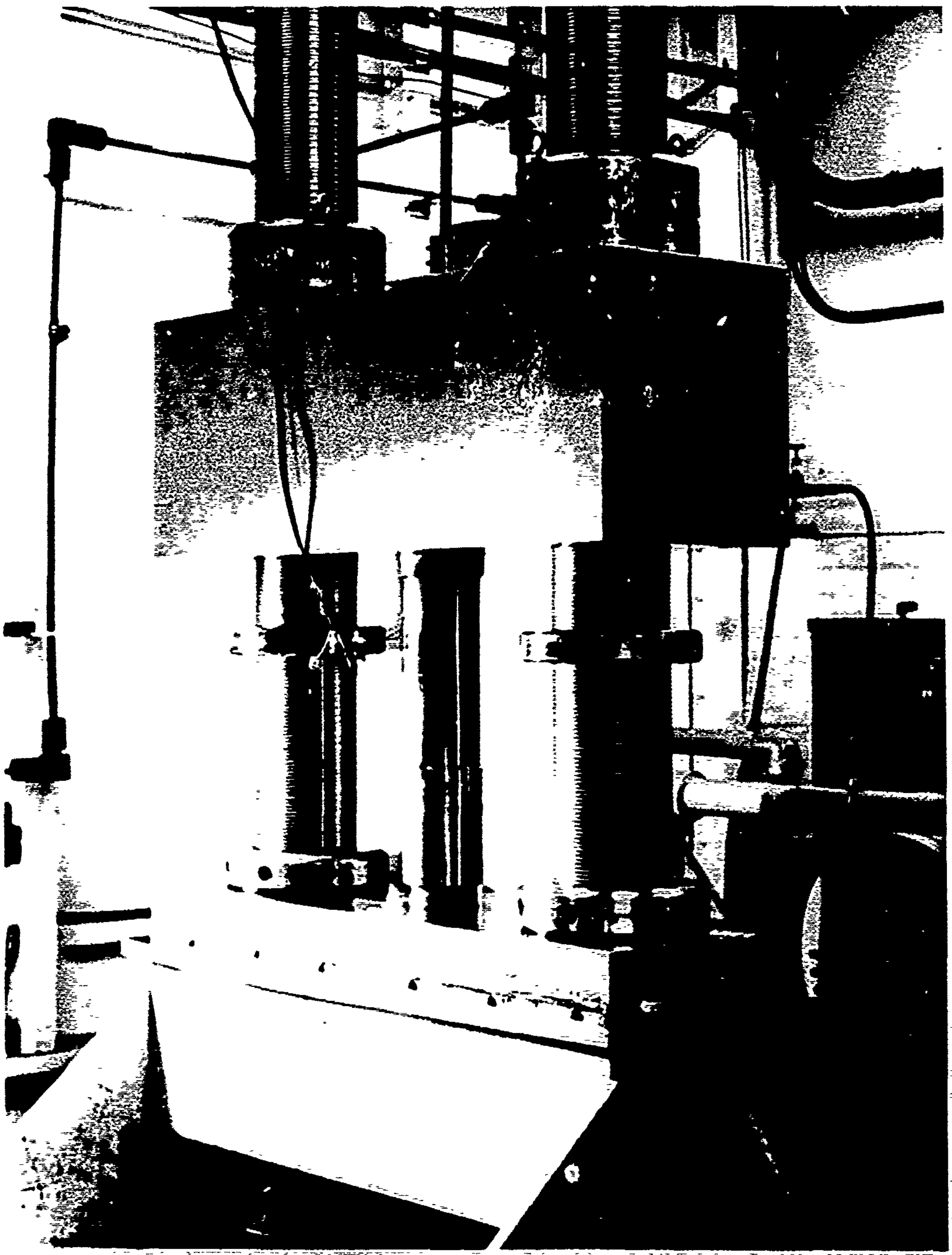


Figure 1d. Specimen with two post press supporting closures.

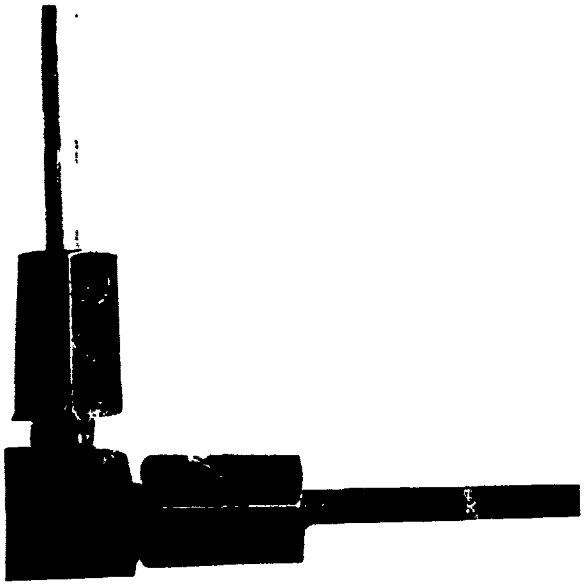


Figure 2a. Pipe and elbow assembly.

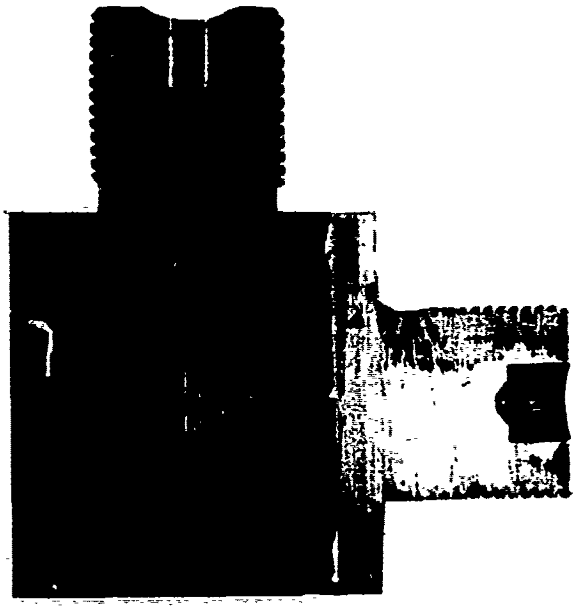


Figure 2b. Elbow fatigue failure.

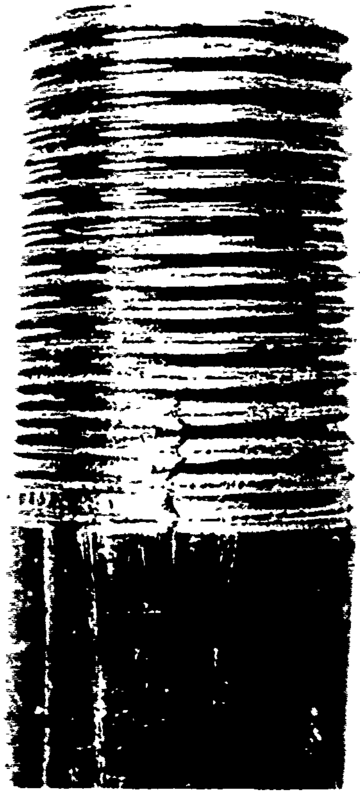


Figure 2c. Pipe fatigue failure.

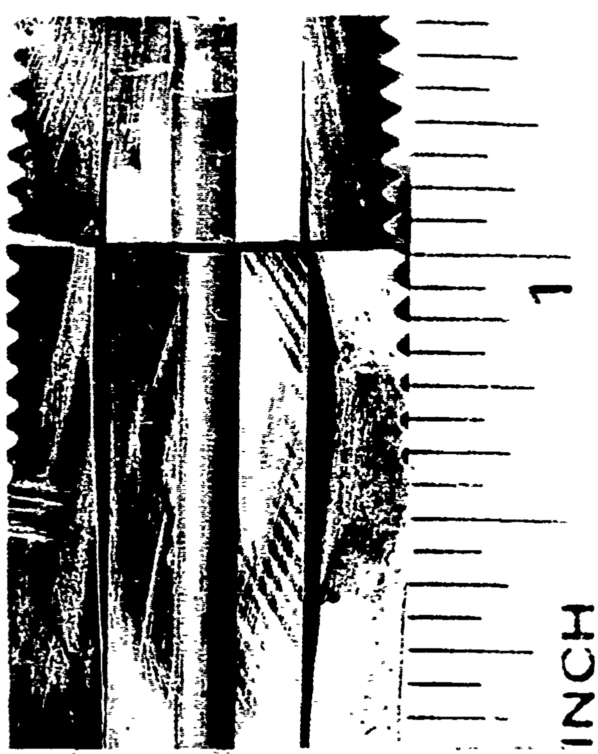


Figure 2d. Internal origin of pipe failure.

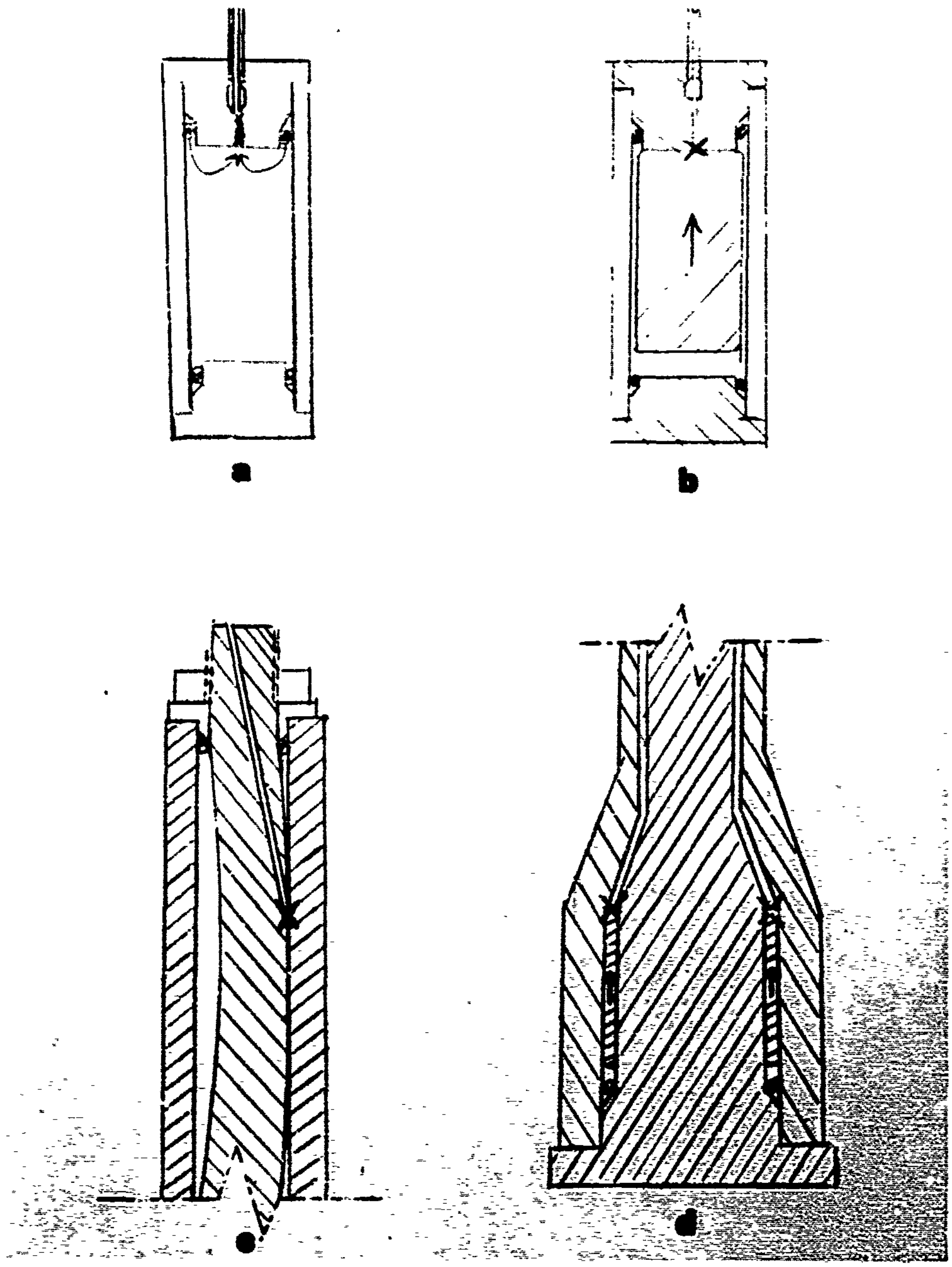


Figure 3. Trapped fluid problem: (a) port plugged with seal material; (b) filler bar blockage; (c) mandrel bend; (d) sleeve shift.

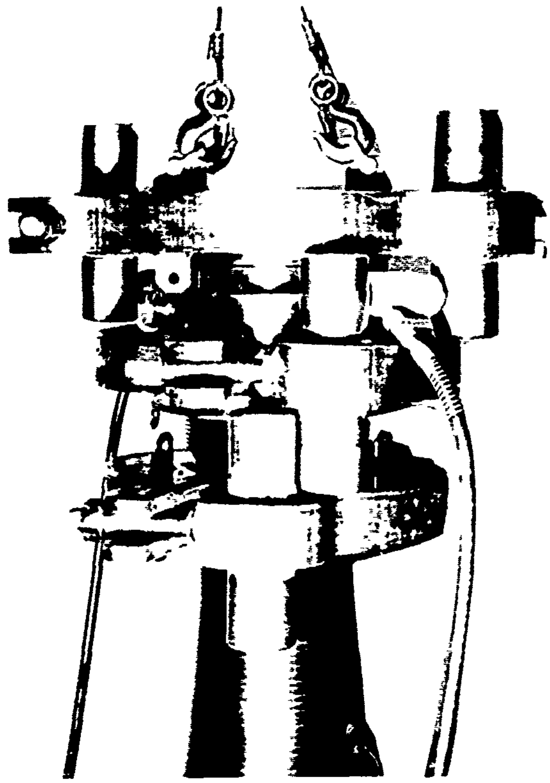


Figure 4a. Unscrewing closure support nut with high torque apparatus (hydraulic drive cylinder is painted white).

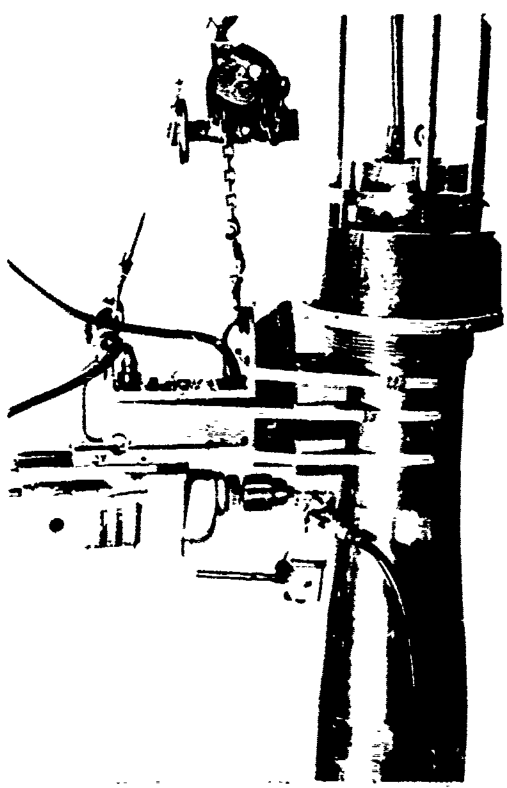


Figure 4b. Remote controlled drilling of specimen wall.

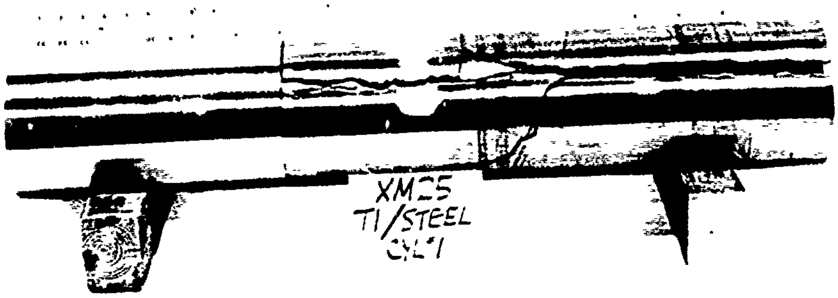


Figure 5a. Brittle material.

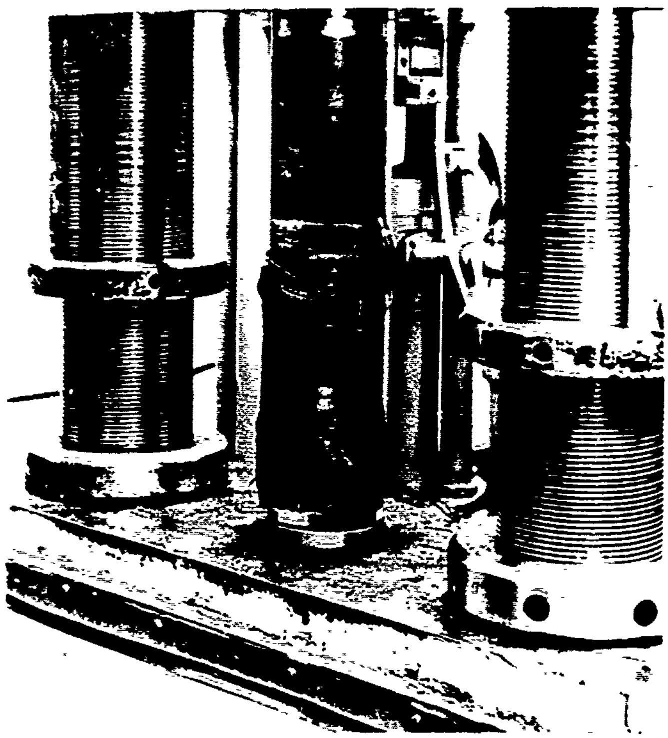


Figure 5b. Composite wrapping.

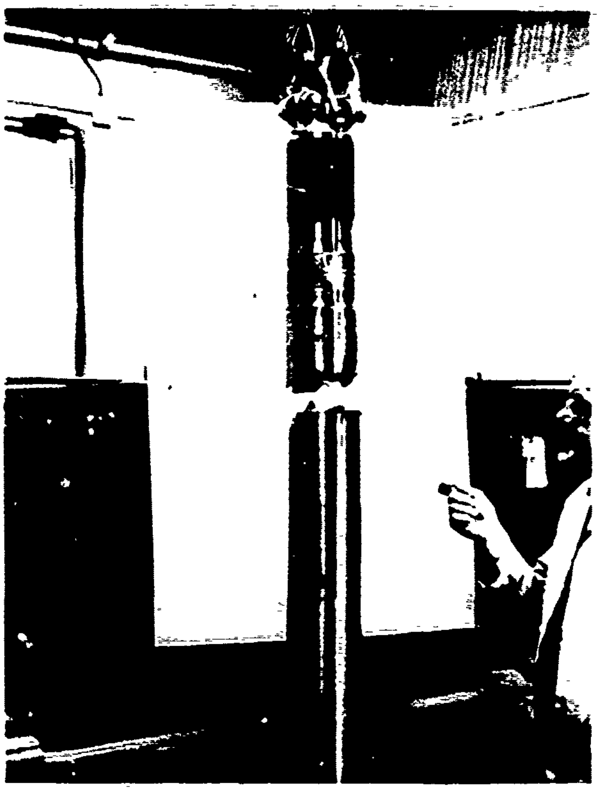


Figure 6a. Fractured mandrel.

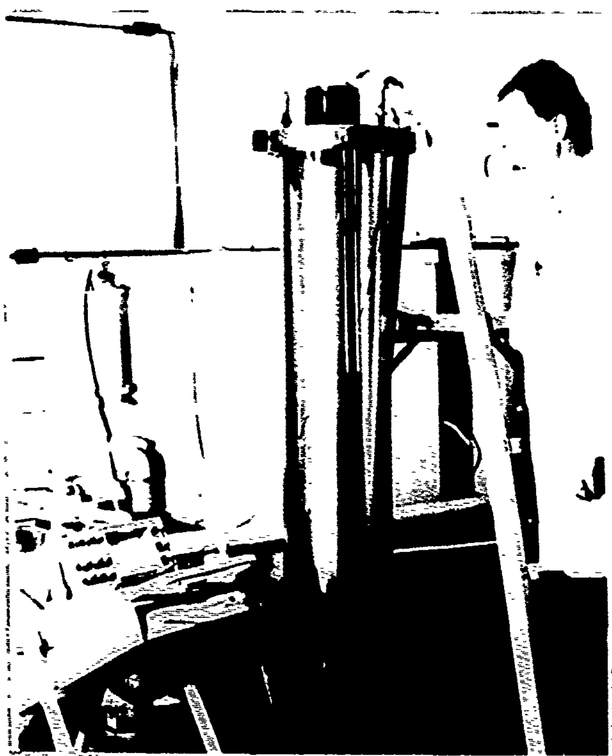


Figure 6b. Ultrasonic inspection of mandrel.

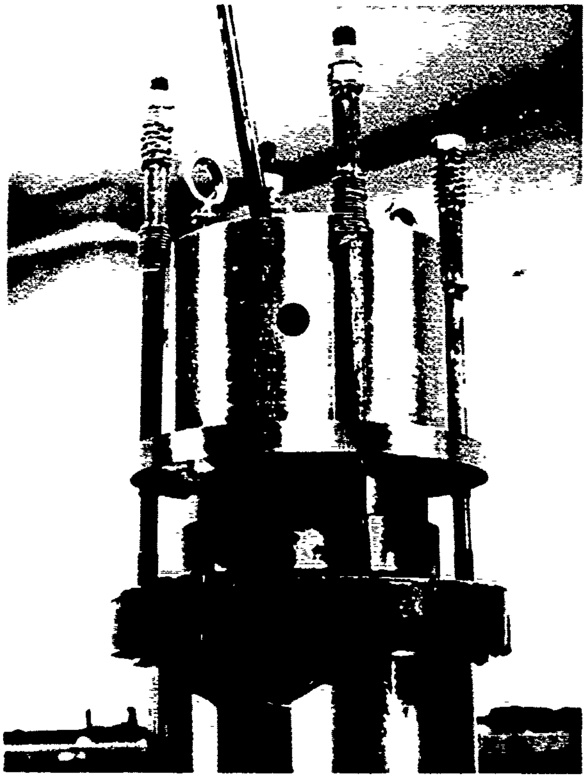


Figure 6c. Shock absorbers.

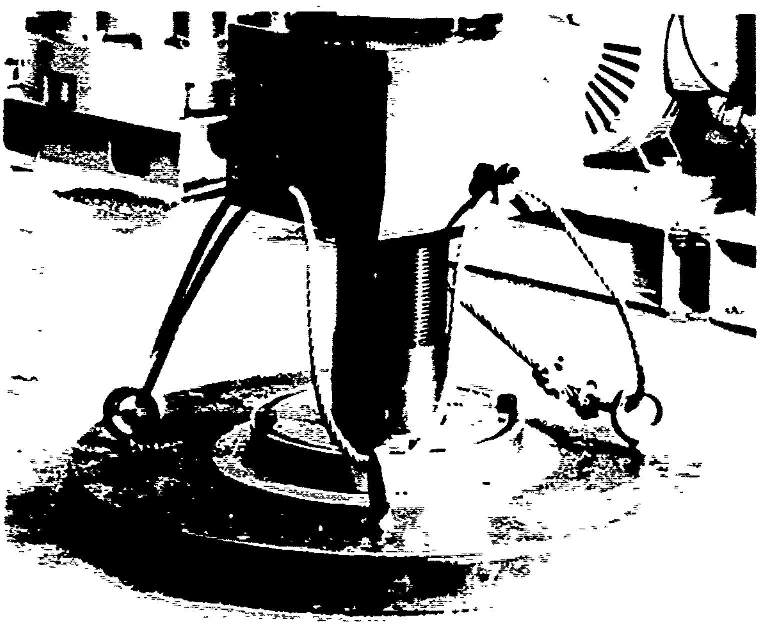


Figure 6d. Restraint cables.

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
CHIEF, DEVELOPMENT ENGINEERING DIVISION	
ATTN: SMCAR-CCB-D	1
-DA	1
-DC	1
-DI	1
-DP	1
-DR	1
-DS (SYSTEMS)	1
CHIEF, ENGINEERING SUPPORT DIVISION	
ATTN: SMCAR-CCB-S	1
-SE	1
CHIEF, RESEARCH DIVISION	
ATTN: SMCAR-CCB-R	2
-RA	1
-RE	1
-RM	1
-RP	1
-RT	1
TECHNICAL LIBRARY	5
ATTN: SMCAR-CCB-TL	
TECHNICAL PUBLICATIONS & EDITING SECTION	3
ATTN: SMCAR-CCB-TL	
DIRECTOR, OPERATIONS DIRECTORATE	1
ATTN: SMCWV-OD	
DIRECTOR, PROCUREMENT DIRECTORATE	1
ATTN: SMCWV-PP	
DIRECTOR, PRODUCT ASSURANCE DIRECTORATE	1
ATTN: SMCWV-QA	

NOTE: PLEASE NOTIFY DIRECTOR, BENET LABORATORIES, ATTN: SMCAR-CCB-TL, OF ANY ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH AND DEVELOPMENT ATTN: DEPT FOR SCI AND TECH THE PENTAGON WASHINGTON, D.C. 20310-0103	1
ADMINISTRATOR DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-FDAC CAMERON STATION ALEXANDRIA, VA 22304-6145	12
COMMANDER US ARMY ARDEC ATTN: SMCAR-AEE	1
SMCAR-AES, BLDG. 321	1
SMCAR-AET-O, BLDG. 351N	1
SMCAR-CC	1
SMCAR-CCP-A	1
SMCAR-FSA	1
SMCAR-FSM-E	1
SMCAR-FSS-D, BLDG. 94	1
SMCAR-IMI-I (STINFO) BLDG. 59 PICATINNY ARSENAL, NJ 07806-5000	2
DIRECTOR US ARMY BALLISTIC RESEARCH LABORATORY ATTN: SLCBR-DD-T, BLDG. 305 ABERDEEN PROVING GROUND, MD 21005-5066	1
DIRECTOR US ARMY MATERIEL SYSTEMS ANALYSIS ACTV ATTN: AMXSY-MP ABERDEEN PROVING GROUND, MD 21005-5071	1
COMMANDER HQ, AMCCOM ATTN: AMSMC-IMP-L ROCK ISLAND, IL 61299-6000	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SMCRI-ENM ROCK ISLAND, IL 61299-5000	1
DIRECTOR US ARMY INDUSTRIAL BASE ENGR ACTV ATTN: AMXIB-P ROCK ISLAND, IL 61299-7260	1
COMMANDER US ARMY TANK-AUTMV R&D COMMAND ATTN: AMSTA-DDL (TECH LIB) WARREN, MI 48397-5000	1
COMMANDER US MILITARY ACADEMY ATTN: DEPARTMENT OF MECHANICS WEST POINT, NY 10996-1792	1
US ARMY MISSILE COMMAND REDSTONE SCIENTIFIC INFO CTR ATTN: DOCUMENTS SECT, BLDG. 4484 REDSTONE ARSENAL, AL 35898-5241	2
COMMANDER US ARMY FGN SCIENCE AND TECH CTR ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY LABCOM MATERIALS TECHNOLOGY LAB ATTN: SLCMT-IML (TECH LIB) WATERTOWN, MA 02172-0001	2

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, US ARMY AMCCOM, ATTN: BENET LABORATORIES, SMCAR-CCB-TL, WATERVLIET, NY 12189-4050, OF ANY ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT'D)

	NO. OF COPIES
COMMANDER US ARMY LABCOM, ISA ATTN: SLCIS-IM-TL 2800 POWDER MILL ROAD ADELPHI, MD 20783-1145	1
COMMANDER US ARMY RESEARCH OFFICE ATTN: CHIEF, IPO P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709-2211	1
DIRECTOR US NAVAL RESEARCH LAB ATTN: MATERIALS SCI & TECH DIVISION	1
CODE 26-27 (DOC LIB) WASHINGTON, D.C. 20375	1

	NO. OF COPIES
COMMANDER AIR FORCE ARMAMENT LABORATORY ATTN: AFATL/MN EGLIN AFB, FL 32542-5434	1
COMMANDER AIR FORCE ARMAMENT LABORATORY ATTN: AFATL/MNF EGLIN AFB, FL 32542-5434	1
METALS AND CERAMICS INFO CTR BATTELLE COLUMBUS DIVISION 505 KING AVENUE COLUMBUS, OH 43201-2693	1

<u>NOTE</u>: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, US ARMY AMCCOM, ATTN: BENET LABORATORIES, SMCAR-CCB-TL, WATERVLIET, NY 12189-4050, OF ANY ADDRESS CHANGES.